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RATIONAL SELECTION OF LOADS FOR CONDUCTORS AND CABLES FOR LOW-VOLTAGE ELECTRICAL NETWORKS

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[Figures are appended]

The loads for conductors and cables, specified by the regulations in force, represent "capacities" or loads calculated under conditions of maximum permissible heating. The tendency to economize on nonferrous metals led to a gradual increase in these loads. Until 1939 they were calculated for conductors with standard rubber insulation starting with a 20 degree centigrade drop in temperature; in 1939, this drop was increased to 30 degrees. In conductors with heatproof rubber insulation, for which the maximum admissible temperature reaches 70 degrees, the drop amounted to 45 degrees. If the ambient temperature is lower than 25 degrees, this circumstance is also used to increase the load.

Regardless of this VES standard in effect until 1938, the conditions for conductor protection by fuses, made it possible to use only 80 percent of capacity. This limitation no longer holds good. Finally, capacities for conductors with cross sections up to 6 square millimeters inclusive, according to VES standards, were considerably lower than even those which corresponded to a drop of 20 degrees centigrade.

As a result, the operating standards for loads for conductors with standard rubber insulation with a cross section of 10 square millimeters and over, safeguarded by cut-out fuses, have increased approximately 54 percent as compared with previous VES standards, while for conductors with heatproof rubber insulation, they have increased 80 percent. The divergence is greater when the ambient temperature is lower than 25 degrees centigrade.

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In the case of small cross sections, the comparative load increase is still greater. For example, for 2.5 square millimeter conductors with standard insulation, safeguarded by cut-out fuses, the maximum load according to VES standards amounted to 15 angstrom units, but, according to standards now in force, it amounts to 27 angstrom units -- an 80 percent increase.

In the first approximation, the average root mean square loads of each element of low-voltage network increased in the same ratio. Hence it may be stated that the operating standards for loads are associated with energy losses on low-voltage networks 2.5 to 3.5 times greater than those corresponding to VES standards. This result compels us to give earnest attention to our expedient operating load standards which exceed American standards, for example, by 40 percent or more. The gravity of the problem of power losses in factory networks is aggravated for the Soviet Union by the fact that the overwhelming majority of our enterprises work on two or three shifts.

Cost of Power Losses and Cost of Nonferrous Products

Until now there has been a widespread idea that power losses should be estimated in relation to comparative prices with some coefficient considerably smaller than unity. There is, however, no basis for such a favorable estimate. This is evident from the following considerations:

a. Losses require the same fuel consumption per kilowatt-hour as useful release of energy; the moment of maximum loss coincides with the moment of maximum load. Hence, losses in a power system represent one of the most unprofitable "consumers".

b. The power consumed in losses in low-voltage networks overloads the installations in all phases of electric systems (generators and circuits).

c. Power losses in networks are very great and, computed from the bus bars of the station to the consumption points, they amount to about 25 to 30 percent of the system's maximum load. Hence the struggle to lower losses, if carried into all phases of electric supply, would liberate a considerable amount of power.

It follows from these considerations that power losses must not be calculated by application of any exemptions. The greater the transformation to which the electric current is subjected, the higher must be their estimate. The power released from low-voltage bus bars, and the power of the losses must be calculated together with a price estimate, not for fuel alone, as has repeatedly been done, but for amortization, repairs, and service of all installations beginning with the electric station and ending with the step-down substations for consumers.

Turning to analyses of the costs of nonferrous metal products, we are confronted by the problem of the so-called "deficit coefficient" of nonferrous metal with respect to electric power. It should be noted that the competent planning departments never gave assent to the introduction of such a coefficient. Comparison of the economic structure of the net cost of electric power and nonferrous metal likewise affords no basis for it.

The main components of the net costs of nonferrous metal are: estimates of the cost of installations and technological equipment for extracting and reprocessing ores, administrative expenses, labor, fuel, and electric power. The components of the cost of electric power represent the same elements plus, to a large extent, nonferrous metal. Hence, there is no principal difference between the economic structure of electric power and non ferrous metal. It follows that, in computations, cost estimates both for power losses and for nonferrous metal products must be made in accordance with standard government prices.

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Methodological Estimate of Economic Loads for Conductors and Cables

To determine the most profitable loads, from the standpoint of operating expenses for conductors in low-voltage networks, it has proven most convenient to employ Kelvin's formula in the following form:

$$J_{ec} = \sqrt{\frac{1000 \cdot \eta_H \cdot 57 \cdot n}{3 \cdot k_t \tau \cdot b}} \qquad (1)$$

where jec is the economic current density; η_H denotes the total annual operating estimates for a low-voltage network, expressed in unit parts; n is the constant of the equation A equals m plus nq, expressing the empirical relation between the cost of the wiring system A (in rubles) and the cross section of the conductor q (in square millimeters). A denotes the total cost of all elements of the wiring system (including erection) which depend on the cross section of the conductor selected, and relating to one meter of a three-phase line; k_t is the coefficient accounting for the rise in conductor resistance resulting from current heating; τ equals $k_1 k_2 tT$ is the annual figure for maximum load utilization, expressed in hours; k_1 is the ratio of the duration of the connected state of the network element under consideration to the duration of the work of the enterprise (for 24 hours); k_2 is the relation, expressed in unit parts, of the root mean square value of the load of a network element while under current and the square of the maximum load; t is the number of working hours of the enterprise per 24 hours; T represents the number of working days per year; b, the cost of the energy on the consumer bus bars in rubles.

In the selection of a cross section for conductors, extensive application of the principle of the least possible operating expenditures is extremely difficult in low-voltage networks consisting of a great many elements. It is a matter not only requiring labor consuming accounting, but also a knowledge of characteristics (including planning and operating) necessary for this accounting, which may present even more difficulties.

As a rule, the economic loads should be taken direct (without any calculations) from a table. Such a table, of course, gives only very approximate solutions. To construct it, we shall start with the working conditions of networks in enterprises of the metallurgical industry. These networks have the advantage of being well-studied and wide-spread and of having average working characteristics as compared with other networks. Moreover, we shall commence with an enterprise which has the most frequently employed voltage--380 volts.

After selecting certain values for the load currents, at which the operating characteristics (k_1, k_2, τ) of the network elements transmitting these currents are sufficiently well-known from actual planning, we shall find it possible to determine the corresponding economic current densities by using Kelvin's formula as noted above. The greater the load current, the greater are the values of k_1, k_2, and, consequently, of τ. It is, therefore, natural to assume that the quantities τ and jec as functions of transmissible current are expressed by a smooth curve.

Guided by the methodology mentioned above, we made a calculation relating to conductors in gas conduits. The results of these calculations, as of all calculations prepared by the Kelvin formula, led to much smaller loads than those actually in use. However, this gap was considerably lessened by increasing the calculated values of the economic current densities about 50 percent. With this, the deviation from the optimum value corresponding to the principle of least operating cost was insignificant and did not exceed 7 or 8 percent.

As a result, for a system working on two shifts, we obtained the curve of economic current densities in Figure 1 and the curve of economic loads in Figures 2.

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The economic loads applicable to conductors in gas conduits can be extended to exposed conductors which are run along brick or concrete walls, since the economic indices of these conductors are very close.

Comparisons of the proposed scale of economic loads with the scale of maximum admissible loads of the "Regulations for the Installation of Electric Plants in Industrial Enterprises" (PUEPP), and also with the American and German scales for loads, are given in the table below.

	Loads for Conduit Layouts		Load for Open Wire Layouts			
Cross Section of Conductors in sq mm	A From Economic Current Density	A According to PUEPP	A From Economic Current Density	A According to PUEPP	A According to American Standards	A According to German Standards
1.0	4	13	4	15	4.9	20
1.5	6	15	6	20	8.4	25
2.5	10	22	10	27	16.9	34
4	15	31	15	36	21.8	45
6	23	37	23	46	27.5	57
10	35	53	35	68	39.4	78
16	52	70	52	92	54	104
25	80	90	80	123	78.9	137
35	105	130	105	152	91.7	168
50	140	150	140	192	117.5	210
70	180	185	180	242	154.2	260
95	223	225	223	292	187	310
120	268	255	268	342	217.2	365
150	320	290	320	392	248.5	415
185	--	--	380	450	308	475
240	--	--	480	532	381.4	560

Study of the table shows that:

1. For conductors laid in conduit, the economic loads are 70 percent less than the loads cited in the "Regulations for the Installation of Electric Plants in Industrial Enterprises" (PUEPP) for cross sections of one square millimeter; 34 percent less for 10 millimeters^2, 6.6 percent for 50 square millimeters. For cross sections of 120 and 150 millimeters^2 the economic load is, respectively, 5 and 10 percent greater than that of PUEPP. In general, starting from 50 millimeters^2 cross sections the economic load approximates that of PUEPP.

2. In exposed wire layouts, the economic load for conductors with one millimeter^2 cross sections is 73 percent less than PUEPP loads and 18 percent less than American loads; for 10 millimeters^2, 49 percent less than PUEPP and 11 percent less than American loads; for 35 millimeters^2, 31 percent less than PUEPP and 16 percent more than American loads; for 95 millimeters^2, 24 percent less than PUEPP and 19 percent more than American loads; for 240 millimeters^2, 10 percent less than PUEPP and 26 percent more than American loads.

It must be emphasized that the PUEPP, American, and German tables are not prepared on the principle of economic loads but on the principle of the maximum permissible temperature for conductors.

This article proves that rationalization of the table of loads effective in the USSR requires essential lowering of loads only for conductors with small and, to some extent, with medium cross sections. It scarcely concerns the other conductors.

Appended figures follow.

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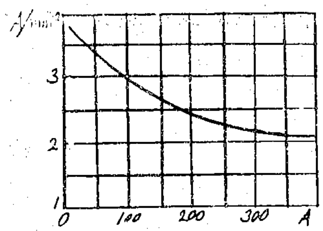

Figure 1. Curve of Economic Current Densities for Po[illegible] Network Conductors in Gas Conduits. The loads on elements of the low-voltage network are along the axis of the abscissa; the economic current density, along the axis of the ordinates.

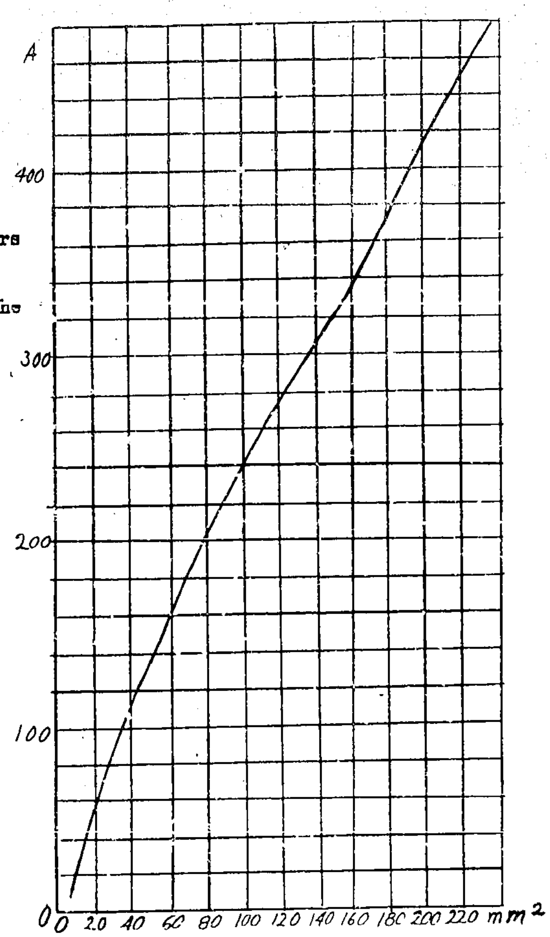

Figure 2. Curve of Economic Loads for Power Network Conductors in Gas Conduits. The cross sections of the conductors lie along the axis of the abscissa; the recommended load, along the axis of the ordinates.

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